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THE PERFORMANCE OF FIRE PROTECTION OF BUILDINGS AGAINST THE FIRES FOLLOWING THE GREAT HANSHIN-AWAJI EARTHQUAKE

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ABSTRACT

High levels of amplitude acceleration (300 gal to 800 gal) and velocity (80 kine) were observed over a wide area at the time of the 1995 Great Hanshin-Awaji Earthquake. The locations where the fires started are almost uniformly distributed in areas where building suffered severe structural damage, mainly areas where the seismic intensity reached seven in JMA scale.

Thanks to the weak winds at the time of the earthquake, the speed of the fire spread was far below that of past urban fires. Seven large fires that destroyed an area of more than 33,000 sq. meters each, broke out in areas with large concentrations of wooden houses. Most of the fire preventive wooden buildings that caught fire did so mainly because fire spread from the building's openings, not from their walls. Most of the cease burning lines in urban areas were wide streets, railways, parks and similar large spaces, rows of buildings of fireproof construction, and fire proof buildings constructed on large building lots. This confirms that it is extremely important to provide more space between buildings and improve buildings' fire proof performance in order to prevent the spread of urban fires.

LARGE NUMBER OF SIMULTANEOUS IGNITIONS

During the first 3 days following the earthquake, more than 200 fires occurred in the Hyogo and Osaka prefectures [1]. Of those, 138 fires took place in Kobe city [2]. Figure 1 shows 150 fire sites where investigations by Building Research Institute were conducted.

The fires started in areas where building suffered severe structural damage. Table 1 shows the relationship between the structural damage of the buildings in which the fires started and the causes of fires. As the structural damages severer, the number of fires increases. In this table causes of fires are categorized into three groups, gas related fires, electricity related fires and other fires. Gas related fires has strong relation to the damage of buildings. Electricity related fires occurred evenly to the structural damage. This indicates that gas related fire most likely occurred when the building was collapsed or severely damaged and as the result the gas pipes were cut or unconnected.

LARGE CONFLAGRATIONS

Of 150 fire sites investigated by BRI, 73 fires involved single building and 77 involved multiple buildings. The number of fire sites less than 1,000 square meters is 33. Seven fires spread over 33,000 square meters. Other 37 fire sites are between 1,000 and 33,000 square meters. Figure 2 shows large conflagrations whose area is over 3,300 square meters in Nagata, Suma, Hyogo, Nada and Higashi-Nada Ward.

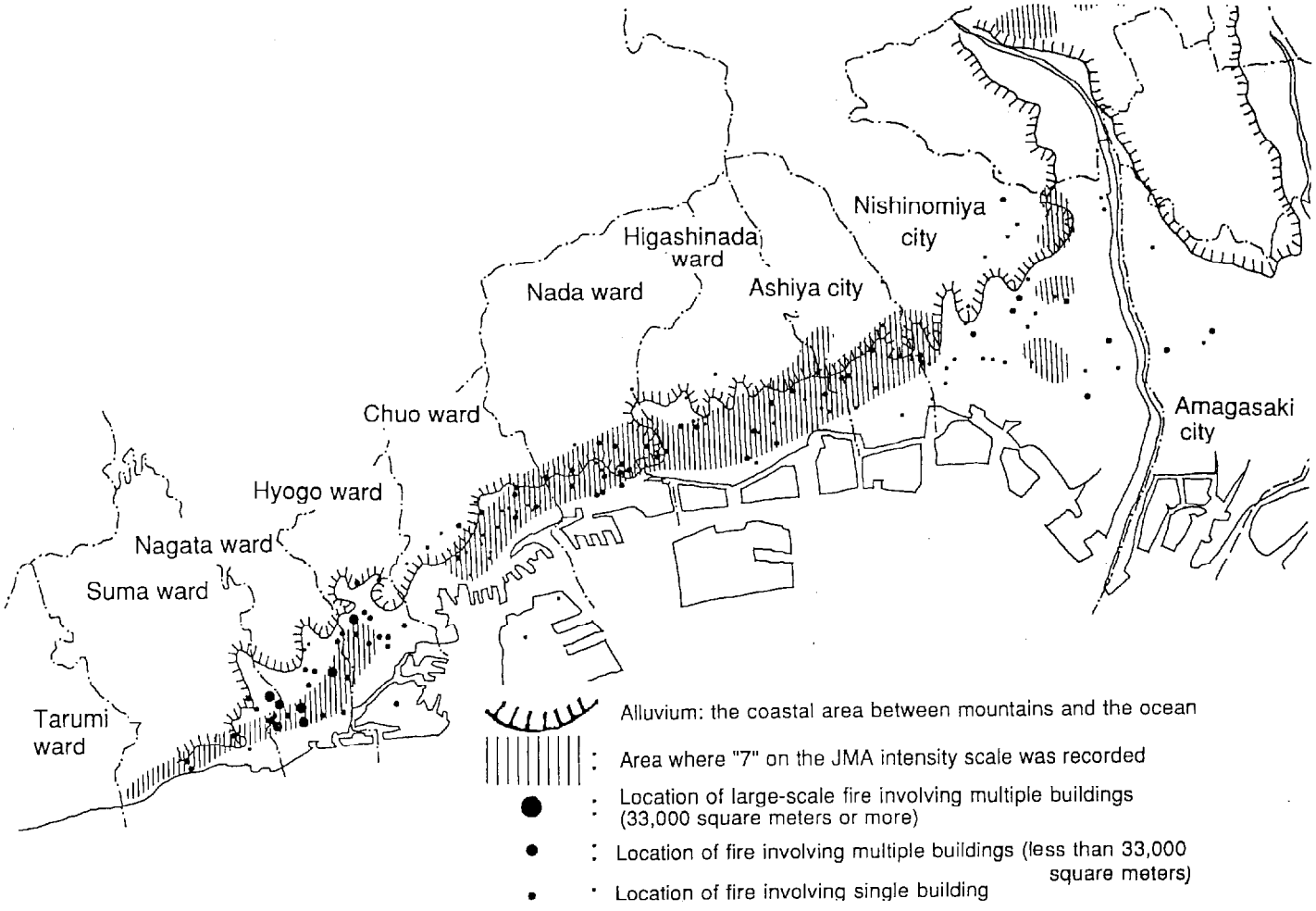
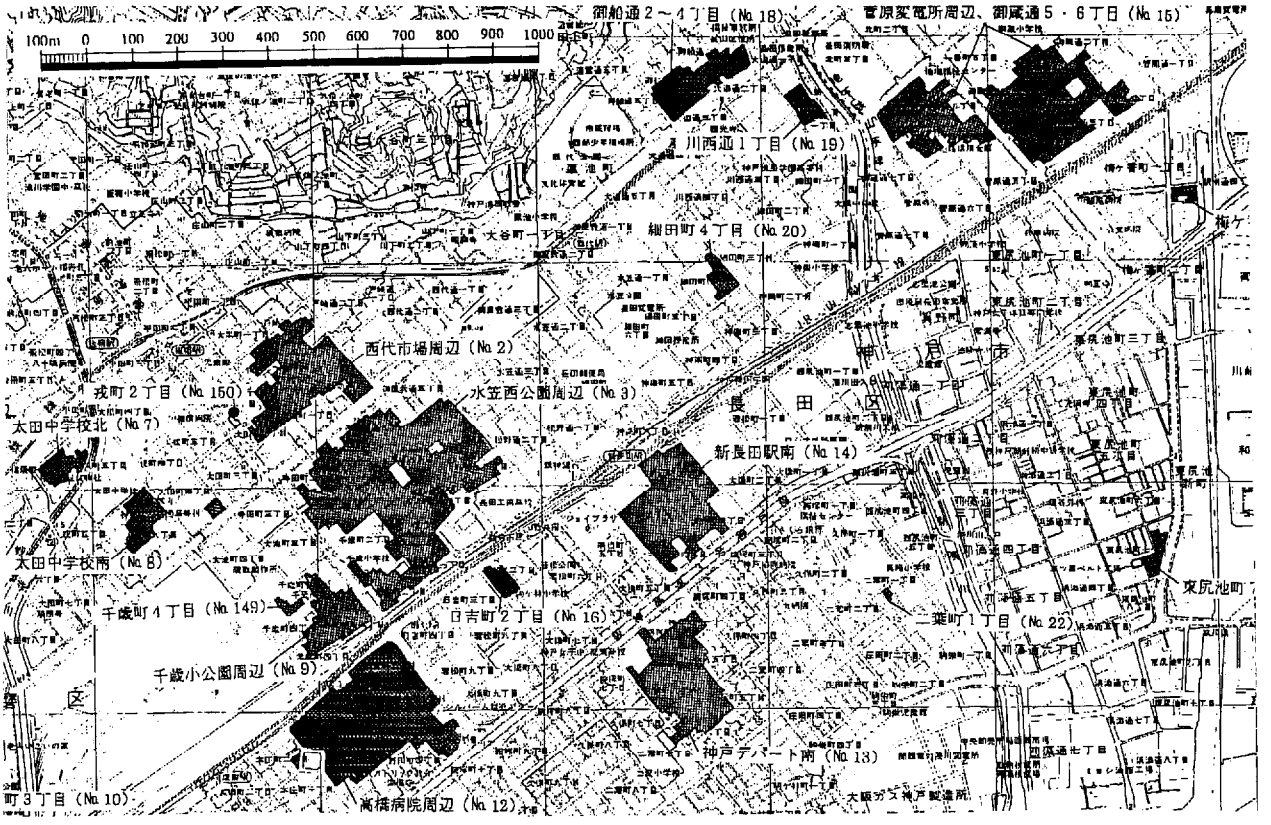


Figure 1. Location of buildings surveyed for fire damage (also shows the alluvium extending from Kobe to Amagasaki and the area where "7" on the JMA intensity scale was recorded)

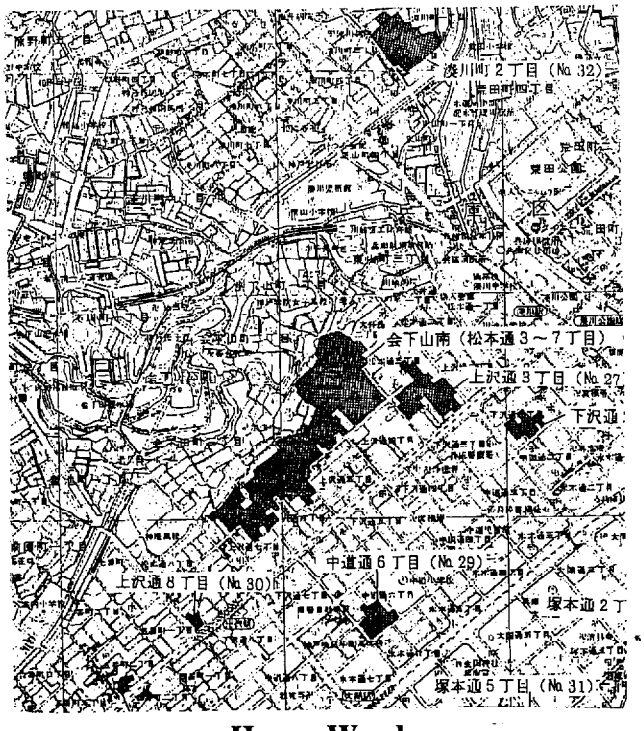
Table 1. The relationship between the structural damage of the buildings and the causes of fires [3)] .

Degree of Structural Damage	Number of Buildings	Gas Related Fires *	Electricity Related Fires *	Other Fires *	Unknown *	Total *
Collapsed or Destroyed	93,567	10 (10.7)	4 (4.3)	11 (11.8)	32 (34.2)	57 (60.9)
Moderate Damage	90,908	5 (5.5)	4 (4.4)	1 (1.1)	14 (15.4)	24 (26.4)
Slight damage or undamaged	358,525	8 (2.3)	18 (5.0)	11 (3.1)	33 (9.2)	70 (19.5)
Unknown		1	6	5	18	30
Total	543,000	24 (4.4)	32 (5.9)	28 (5.2)	97 (17.7)	181 (33.3)

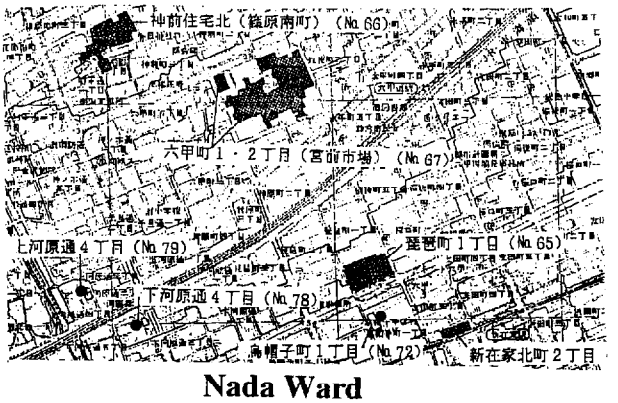
* Number of Fires (10^{-5} Fires per Building)



Nagata and Suma wards



Hyogo Ward



Nada Ward

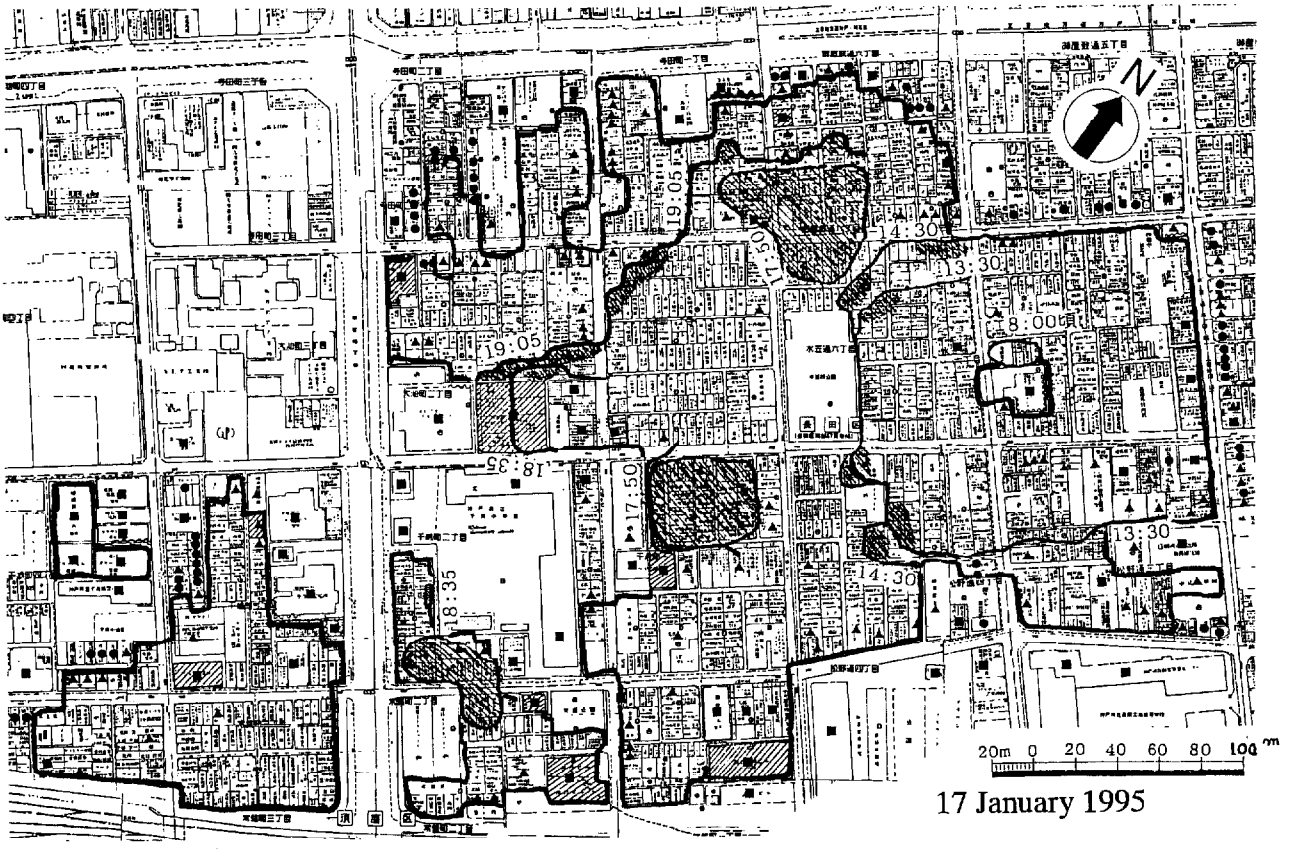
Higashi-Nada Ward

Figure 2. Large Conflagrations in Kobe City

VELOCITY OF FIRE SPREAD AND WIND

Figure 3 shows an example of fire spread recorded by news videos. Fire spread was relatively slow, averaging about 20 to 30 meters per hour. The main reason for this slow speed was that there was a slow wind and sometimes no wind on the day of the earthquake as shown in Figure 4. The average wind velocity in Kobe was 2.6 meters per second.

Figure 5 indicates the relation between the wind velocity and the velocity of fire spread. When the wind velocity is higher than 3 meters per second, the velocity of leeward fire spread increases obviously.



: Partially burned building
: Area burned at the same time
: Counter line at certain time

Index for building structure

- ■ : Fire resistive building
- ▲ : Semi-fire resistance building
- ● : Wooden building with non-combustible materials on the exterior wall
- ○ : Wooden building without non-combustible materials on the exterior wall

Figure 3. Contour Line of Fire Spread (Fire Site around Mizukasa Nishi Park)

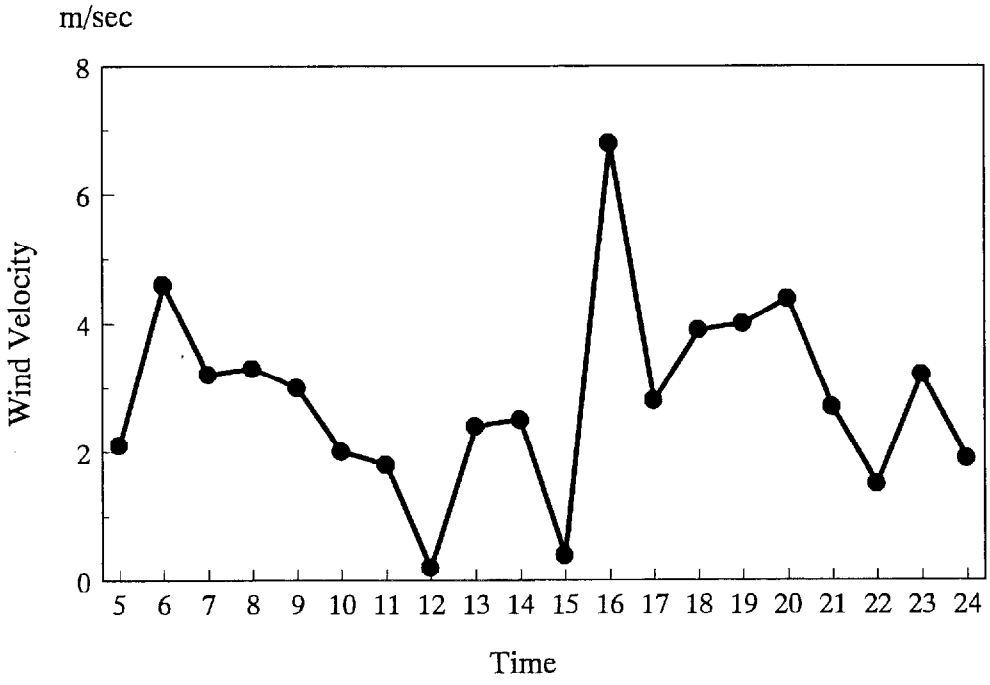


Figure 4. Wind Velocity at Kobe Meteorological Observatory in Chuo Ward on the Day of the Earthquake

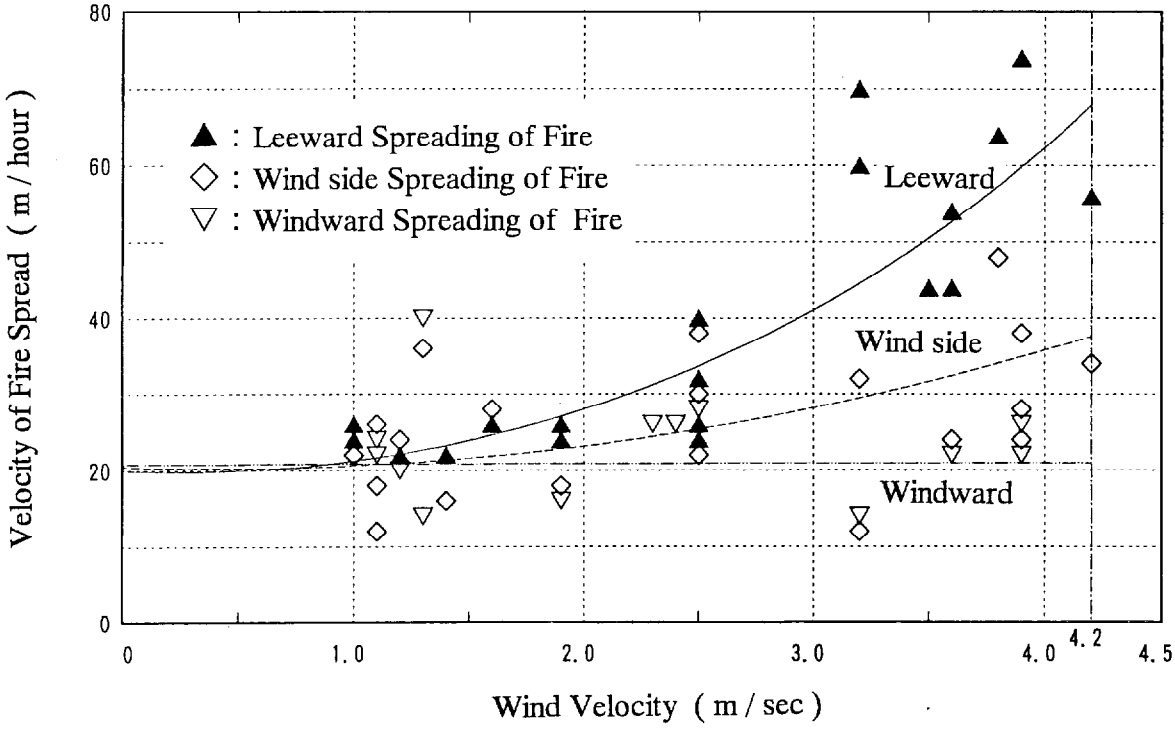


Figure 5. Relation between the wind velocity and the velocity of fire spread [4)]

There is some evidence that the fire spread faster in the blocks of wooden buildings without non-combustible materials on the exterior wall than in the blocks of wooden buildings without non-combustible materials and in the blocks which have some fire resistive buildings [5].

FIRE SPREAD MECHANISMS

The fires spread widely because the buildings were so close together especially in Nagata and Hyogo wards as shown in Figures 6, 7 and 8. In those fire sites in Nagata and Hyogo wards, there were a lot of wooden dwellings whose exterior walls were not covered with non-combustible materials. Although many of the conventional post & beam construction dwellings had been covered with non-combustible materials, they were severely damaged by the earthquake. In the case when the fire preventive wooden buildings constructed appropriately in accordance with the present aseismatic standards and suffered a little damage, most of them that caught fire did so mainly because fire spread from the building's openings, not from their walls [6].

The combustible contents of the houses, synthetic rubber in small shoes factories especially in Nagata ward and collapsed buildings on the street contributed to the fire spread as shown in Figure 10.

There are at least 20 cases where new ignitions were caused by burning wood and embers flying through the air [7]. Because fireproof roofing was shaken down by the earthquake, it was easy to ignite with burning wood and embers in those wooden house areas, although people out there extinguished most of the small ignitions.

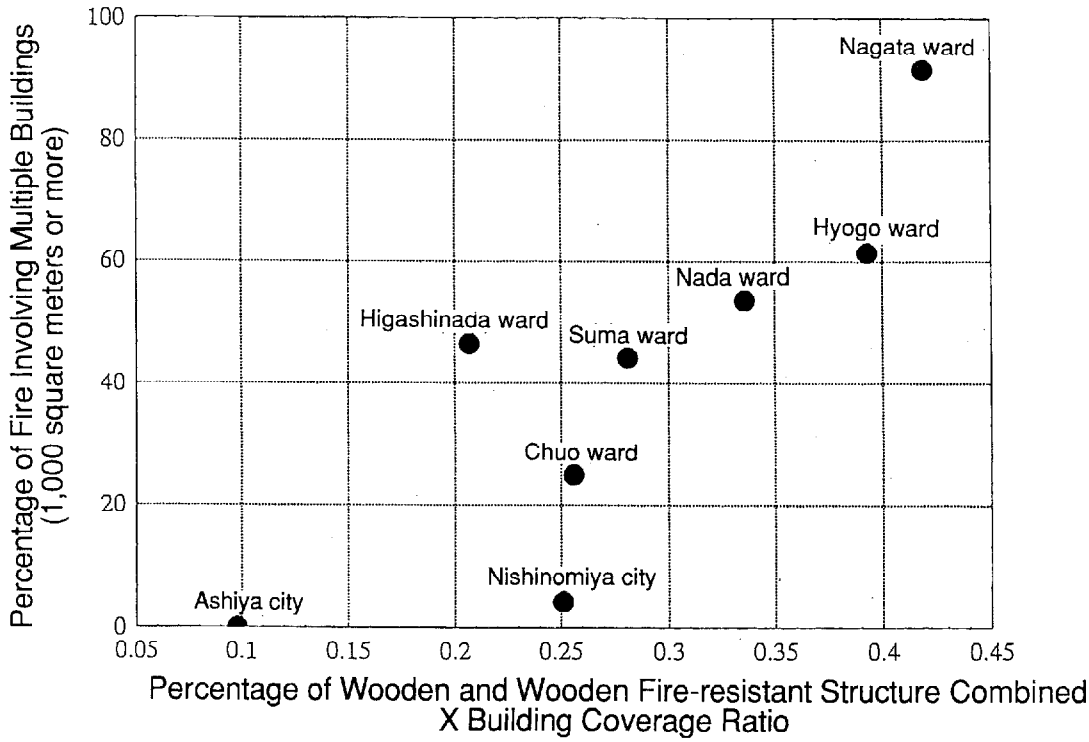


Figure 6. Relation between Percentage of Fire Involving Multiple Buildings and Wooden Building Coverage Ratio (Ward and City)

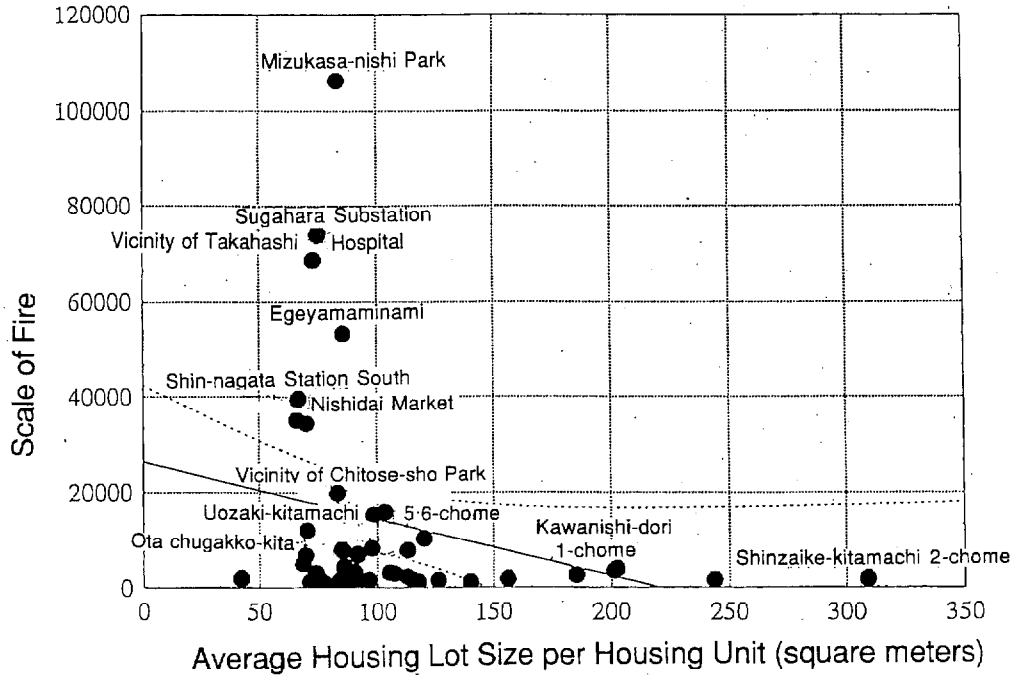


Figure 7. Relation between Scale of Fire and Average Housing Lot Size per Housing Unit (Fire Site)

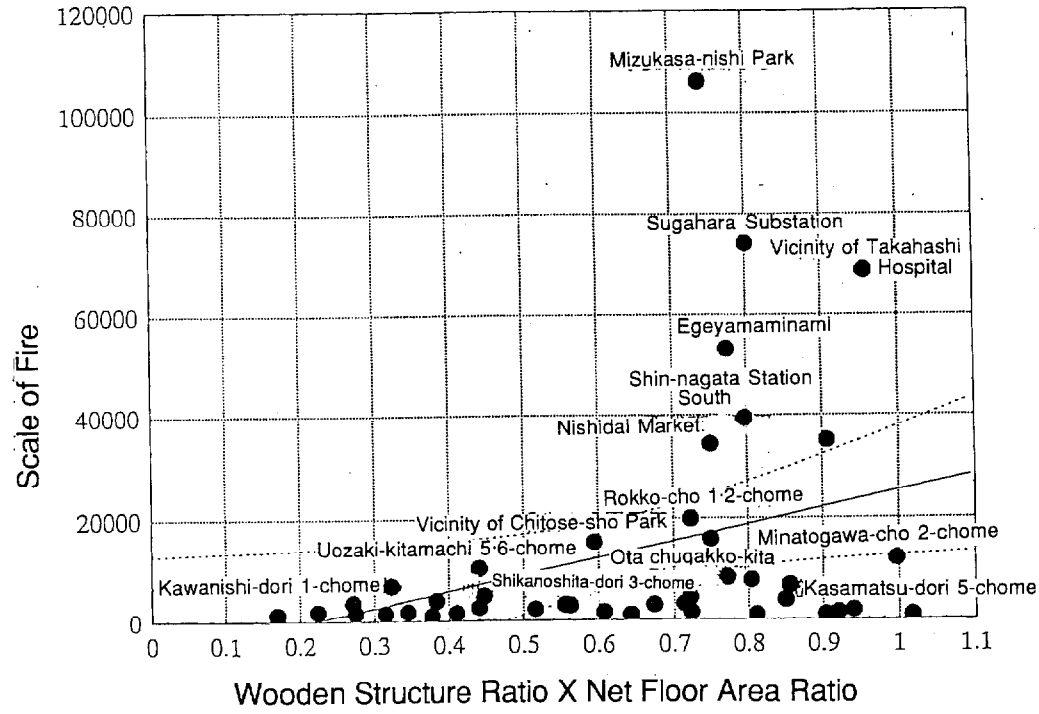
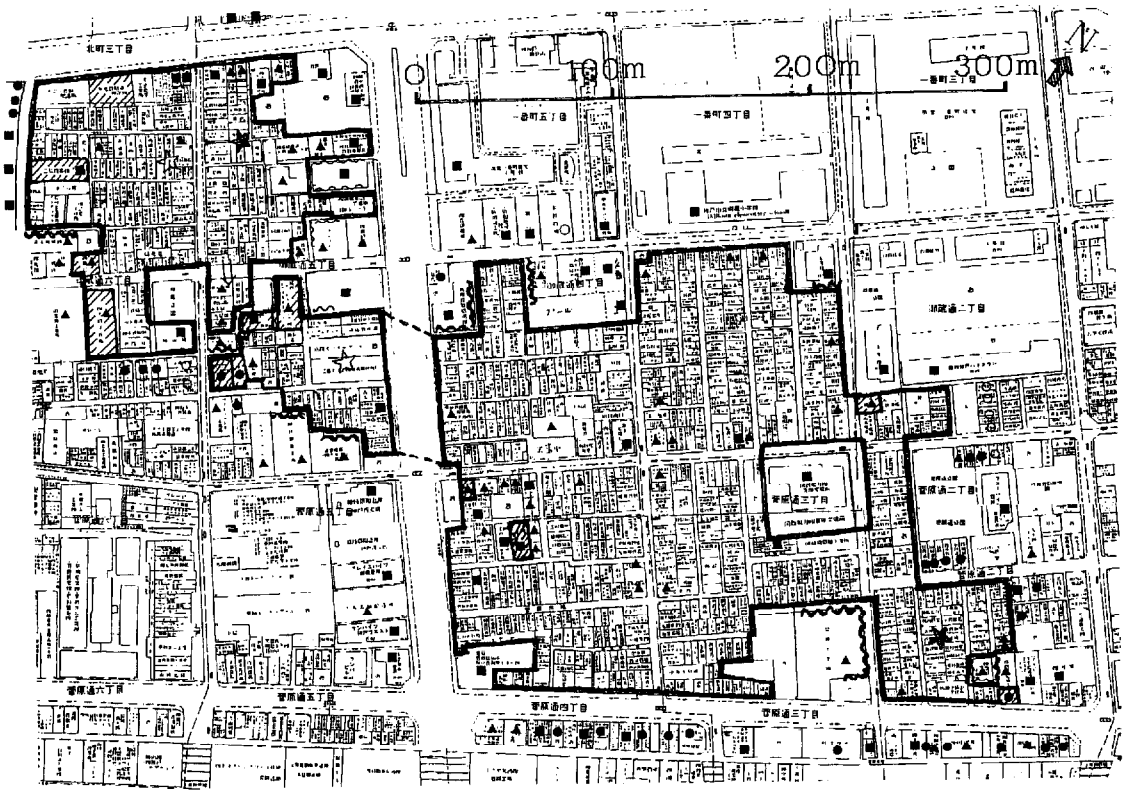


Figure 8. Relation between Scale of Fire and Wooden Structure Floor Area Ratio (Fire Site)



Index for building structure

- ■ : Fire resistive building
- ▲ : Semi-fire resistance building
- ● : Wooden building with non-combustible materials on the exterior wall
- ○ : Wooden building without non-combustible materials on the exterior wall

Index for Ignition

- ★ : Fire origin (an eye-witness)

Index for Fire Spread

- ☆ : Ignition by burning wood and embers flying through the air (Estimated by the evidence of sight)
- ⇐ : Fire Spread through the collapsed building on the street by fire

Index for Fire-Arresting Line

- —— : Fire spread boundaries
- ▨ : Partially burned building
- ∿∿ : Fire damage only on the exterior wall

Figure 9. Fire Site around the Sugawara Market

FIRE STOP FACTORS

Most of the cease burning lines in urban areas were wide streets, railways, parks and similar large spaces, rows of buildings of fireproof construction, and fire proof buildings constructed on large building lots.

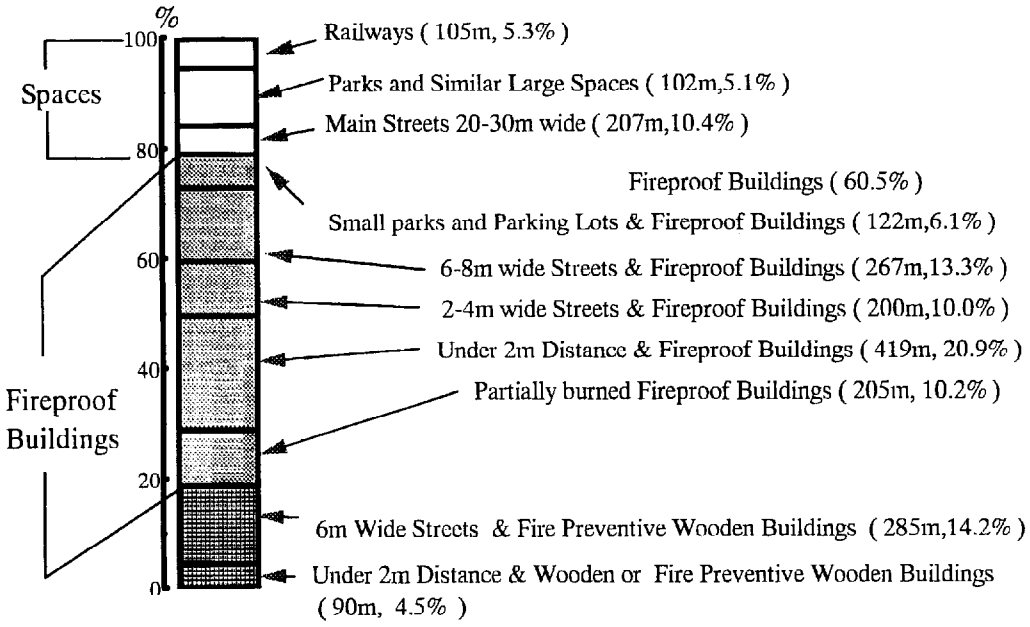


Figure 10. Fire Stop Elements at the Fire Site around the Mizukasa Nishi Park (BRI)

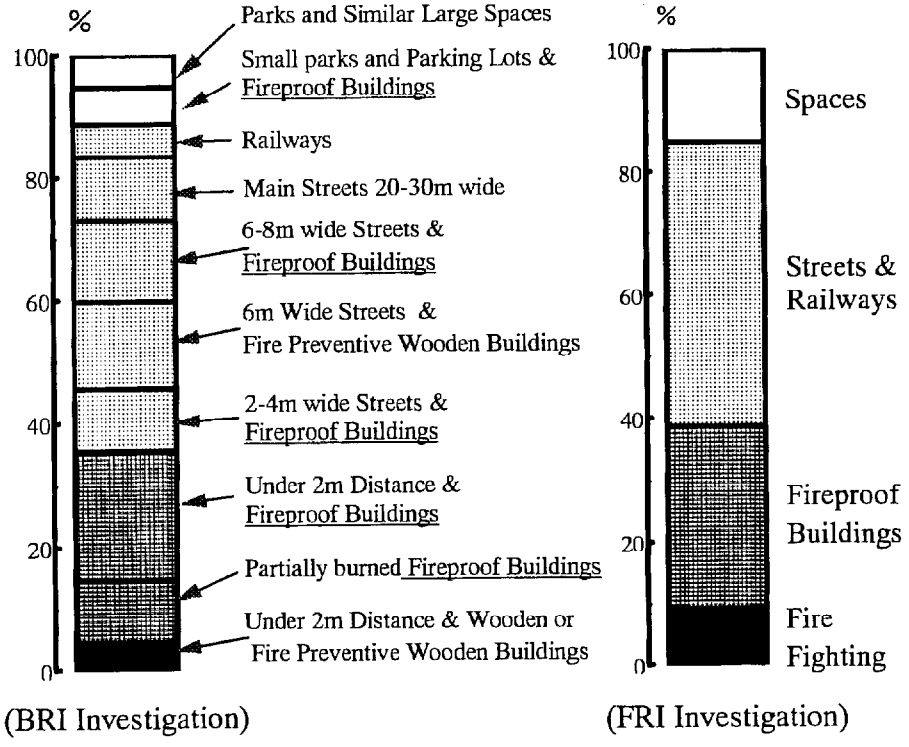


Figure 11. Fire Stop Factors Comparison between the result of BRI investigation and FRI investigation at the Fire Site around the Mizukasa Nishi Park

Figure 10 shows fire stop elements at the fire site around the Mizukasa Nishi Park. This fire site was a typical residential area with large concentrations of wooden houses. About 60 percent of the cease burning lines consisted of fireproof buildings.

Figure 11 shows a comparison between the result of BRI investigation and FRI investigation at the Mizukasa Nishi Park. To make it the same definition, spaces factor around the park was omitted from the result of FRI investigation.

The streets & railways factor is the main fire stop factor at the FRI investigation. The fireproof buildings factor is the main fire stop factor at BRI investigation. Had the buildings along the 6-8 m streets been wooden buildings, those wooden buildings at the cease burning lines would have been easily ignited. From this point of view, improvement of fire protection of buildings is more important than streets widening.

CONCLUSION

Fortunately the wind was weak during the first hours after the earthquake and catastrophic fires such as the 1923 Great Kanto Earthquake Fire were avoided. Further studies including detailed analysis of fire spread mechanisms and experimental studies for the conditions with strong winds are necessary for the disaster prevention planning. It is necessary to promote the improvement of urban residential areas by, for example, carrying out the systematic reconstruction of buildings in areas with high concentrations of decrepit wooden dwellings.

REFERENCES

1. Fire Research Institute ; Data base of the fires following the 1995 Southern Hyogo Prefecture Earthquake.
2. Fire Department of Kobe City ; Fires following the 1995 Southern Hyogo Prefecture Earthquake, 14 April 1995.
3. Building Research Institute ; The Final Report of Investigation on the 1995 Southern Hyogo Prefecture Earthquake, March 1996.
4. Tokyo Fire Department ; The Investigation Report on the Fires in Kobe City following the Southern Hyogo Prefecture Earthquake, December 1995.
5. Murosaki, Y. et al at Kobe Univ. and Institute of Environment & Safety Planning; Fire Spread in the 1995 Great Hanshin and Awaji Earthquake, 28 March 1995.
6. Sugawara Shinichi ; Damages at the openings of Houses by the fires following the Southern Hyogo Prefecture Earthquake, December 1995.
7. Murosaki, Y.; "Problems around the fires following the 1995 Southern Hyogo Prefecture Earthquake", Proceedings of the Symposium on Earthquake and Fires, Japan Association for Fire Science and Engineering, 26 May 1995.
8. Fire Research Institute ; The Investigation Report on the Fires in Kobe City following the Southern Hyogo Prefecture Earthquake, March 1995.

Discussion

William Pitts: I know there has been some work in Japan on modeling the spread of urban fires, and it seems like you have enough data to do some sort of comparisons. Have you made any comparisons of model with fire spread in the urban environment?

Akihiko Hokugo: This is the very topic that Dr. Tanaka is supposed to conduct some research from now on.

Takeyoshi Tanaka: We haven't started the construction of modeling of fire spread yet. We just started to collect some basic data.

Henri Mitler: Were you able to establish any statistics on how many of those fires that were induced in fire-proof buildings penetrated through broken windows?

Akihiko Hokugo: Since we had to deal with so many buildings, it was quite difficult for us to understand what kind of actual structure those buildings had. Therefore, we feel that it will be difficult to collect some meaningful statistics concerning that specific point.

Edward Zukoski: Is there any good data on the rate of fire propagation through buildings that were very severely damaged and sort of flattened by the earthquake as compared to buildings that were not very severely damaged?

Akihiko Hokugo: According to the statistics collected by the University of Kobe, when they compared the external damage of the buildings as a result of fire, in terms of fire resistant buildings, the more destruction those buildings experienced, the higher the extent of fire spread to upper floors. So if you compare individual buildings, the destroyed and severely damaged buildings tend to allow the fire to spread to the upper floors.